CATALYTIC OXIDATION OF OLEFINS IN THE VAPOR PHASE

by

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B. S., Kansas State College of
Agriculture and Applied Science, 1939

A THESIS

submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

Department of Chemistry

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

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INTRODUCTION

Petroleum refining gives an enormous and cheap supply of cracked gasoline fractions for organic synthesis. However, most of the research work has been done on such reactions as chlorination with subsequent hydrolysis, esterification, nitration, and hydration. Often, these methods require expensive reagents. Vapor phase oxidation, on the other hand, has the advantage that air is used. This raw material is both cheap and easy to handle.

By investigating the conditions favorable to the production of maleic acid, it is hoped that the practical application of hydrocarbon chemistry will be increased. A process for the low cost production of maleic acid is desirable because of the numerous uses of this acid. Maleic acid does not have the volume demand that such oxidation products as phthalic anhydride, anthraquinone, and benzoic acid do. However, a number of novel uses have been developed and proposed, and, with the preparation of useful derivatives, increased consumption is probable.

Maleic acid may be readily converted to malic acid by heating in aqueous solution under pressure. Downs (1)

states that sodium malate is recommended in foods for persons who cannot tolerate sodium chloride. He also states that malic acid may be used in place of citric and tartaric acids as an organic acidulent, and that calcium malate is used to precipitate calcium tartrate in wine making. Succinic acid, derived by reduction, is being used in the formation of certain resins which are described by Bradley, Kropa, and Johnston (2); and maleic anhydride resins, as described by the same authors, are finding increasing use in the formation of varnishes. Vincent (3) found that maleic acid condenses with poly-hydroxy alcohols to give resins for specialized uses. Investigations of terpene-maleic anhydride resins by Littmann (4) show new uses for this plastic. Downs (1) found great promise of the use of maleic anhydride in the Diels-Alder synthesis which gives new acid anhydrides in quantitative yields by direct addition. He states that maleic acid is useful as an antioxidant for fats since its effective concentration and solubility are both 1 part in 10,000 of fat, and any excess is merely filtered off. Miscellaneous uses are the treatment of cracked gasoline and for leather tanning to replace lactic, formic, or acetic acids.

REVIEW OF LITERATURE

Maleic acid has been produced by Sessions (5) and by Wilas and Walsh (6) by the catalytic oxidation of furfuraldehyde. Oxidation of cycloparaffins by Wilas and Walsh (7) gave maleic acid. Faith and Schaible (8) succeeded in producing maleic acid from crotonaldehyde, and unsaturated acids were catalytically oxidized by Faith and Yantzi (9) to give maleic acid.

REACTIONS OF OLEFINS

Olefins (10, p. 247) may polymerize, rearrange to isomeric hydrocarbons, and decompose. At high temperatures, all three reactions may go on simultaneously. With increasing temperatures, the first reaction is generally polymerization. With more heat, isomerization is the predominant reaction while, at still higher temperatures, decomposition takes place. The presence of a double bond (C=C) exerts a marked influence on the strength of the other carbon-carbon bonds in the molecule. In the system, $C-C^{\alpha}-C^{\beta}-C$, it is considered that the $C^{\alpha}-C$ has greater stability than the $C^{\beta}-C$ bond.

Oxidation reactions are generally thought to be mostly the formation of peroxides (10, p. 297). Lewis (11) found that amylene is oxidized to a peroxide which decomposes readily giving rise to further products such as aldehydes which, in the presence of oxygen, are further oxidized to CO_2 and CO. He heated amylene during a period of 2½ hours up to a temperature of 240°C. when 8.6 to 44.5 per cent of the hydrocarbon was oxidized to CO_2 and CO.

METHODS AND APPARATUS

Analytical Methods

Maleic acid was determined by the barium maleate monohydrate method as modified by Faith and Schaible (8). Check analyses of known mixtures of maleic acid were accurate within one per cent. The purity of the barium maleate monohydrate was proved by the quantitative conversion to barium sulphate in the usual manner.

Analysis

Calculated for $C_4H_2O_4Ba \cdot H_2O$, Ba = 50.98 per cent.

Amylene, found: 51.80 per cent, 50.20 per cent, 51.40 per cent, 50.80 per cent.

Methyl Pentene, found: 51.60 per cent, 51.30 per cent, 50.30 per cent.

Heptene, found: 50.30 per cent, 50.10 per cent.

Caprylene, found: 50.32 per cent, 50.74 per cent, 51.33 per cent, 51.16 per cent.

Melting Points

The solid products which sublimed on the walls of the ice-cooled condenser gave the following melting points: amylene, 132-133°C.; methyl pentene, 133-4°C.; heptene, 134-5°C.; and caprylene, 133-4°C.

Aldehydes were determined by the neutral sulphite method. Carbon dioxide was determined by scrubbing an aliquot portion of the exhaust gases with barium hydroxide, filtering, and washing the barium carbonate formed. This precipitate was then dissolved in hydrochloric acid and again precipitated as barium sulphate. The carbon dioxide determined on each run was corrected for error due to absorption of the gas from the atmosphere during manipulation. Similarly, the carbon dioxide from the air

used for oxidation was subtracted, and then the portion due to oxidation of amylene to maleic was also subtracted. Finally, the result was divided by five to give the moles of amylene completely oxidized to carbon dioxide. Amylene oxidation to aldehydes and other acids was not considered in the above calculation because the molecular weights of these products are unknown. Other acids were determined by difference from the titrated and gravimetric determinations of maleic acid, and they are recorded as maleic acid.

Apparatus

The apparatus used was of the usual type for oxidation reactions. Primary air was passed through a drying tower and its volume measured by means of a calibrated flowmeter. The hydrocarbon vapors were brought to the reaction tube by means of dry nitrogen which was bubbled through the liquid olefin. In order to fix the vapor pressure, the olefin was held at a constant temperature. The nitrogen emerged with a constant partial pressure of hydrocarbon, and the total volume of olefin was regulated by the flow of nitrogen. Measurement of the flow of nitrogen was by means of a calibrated flowmeter. At the

entrance to the catalyst tube, the primary air for oxidation was mixed with the nitrogen-olefin mixture. A mixture of vanadium oxides, the catalyst, was held in a pyrex tube 2.5 centimeters in diameter and 36 centimeters long. Catalyst lengths were varied from 8 to 36 centimeters.

Heat to maintain constant temperature in the reaction chamber was applied by placing the tube inside a small electric furnace with a bank of lamps for control. Temperature measurement was by means of a movable thermocouple inside a small pyrex tube projecting into the catalyst chamber to an ice-cooled flask. Solid product sublimed on the walls of this vessel and on the walls of the air cooled flask into which the vapors flowed next. Finally, the gases were bubbled through a flask partly filled with water, and the remaining maleic acid was recovered.

SOURCE OF MATERIALS

The technical amylene and the caprylene used were from Eastman Kodak Company. The heptene and methyl pentene were obtained from Carbide and Carbon Chemicals Corporation.

RESULTS

Space Velocity

In flow systems, the fractional conversion is determined by the time during which the reactants are in contact with the catalyst (12, p. 92). The time of contact is measured by the rate of flow and the quantity of the catalyst. It can be treated in terms of space velocity. Space velocity is defined to be the volume of gas at standard temperature and pressure passing through a given volume of catalyst space per hour. It may be referred to any principal constituent of the reacting mixture. The yield of desired product in unit time per unit volume of catalyst per passage is the space-time-yield. This is the product of the fractional conversion by the space velocity. The slope of the curve of space-time-yield versus space velocity gives a weighted average fractional conversion. The initial portion of the curve represents the low space velocity region in which equilibrium conditions are always attained, the space-time-yield here being directly proportional to the space velocity.

At higher space velocities, the time of contact is shorter than the time required to establish equilibrium and the fractional conversion becomes a function of space velocity. The conversion decreases with increasing space velocity, and the curve drops.

Another factor is the space occupied by the catalyst itself, since the free cross-sectional area determines the actual velocity through the catalyst space. Water displacement showed that the catalyst used was 13.5 per cent solid. The time of contact based on the total gas flow was from 0.4 to 1.8 seconds. All the space-time-yield versus space velocity curves were based on amylene flow since plots based on air flow gave no correlation of results.

Effect of Space Velocity on Maleic Acid Production

Plots of space-time-yield against space velocity for maleic acid production from amylene are given by Figures 1 to 4 inclusive. One end of the curve is fixed by the origin, and the rest of the line is taken to give as nearly as possible the average space-time-yield at each space velocity. The conversion is then given by the

slope of the line.

At 360°C., 420°C., 465°C., and 505°C., the conversions to maleic acid were 0.185, 0.190, 0.150, and 0.172, respectively. The vertical spread at each of these temperatures is about 0.5 units of space-time-yield.

Effect of Space Velocity on CO_2, Other Acids, and Aldehydes

Figures 5 to 8, inclusive, are plots of space-time-yield versus space velocity for CO_2. A definite upward trend is noticeable, but the spread is about 0.5 units of space-time-yield.

At 360°C., 420°C., 465°C., and 505°C., the conversions to CO_2 were 0.11, 0.20, 0.16, and 0.15.

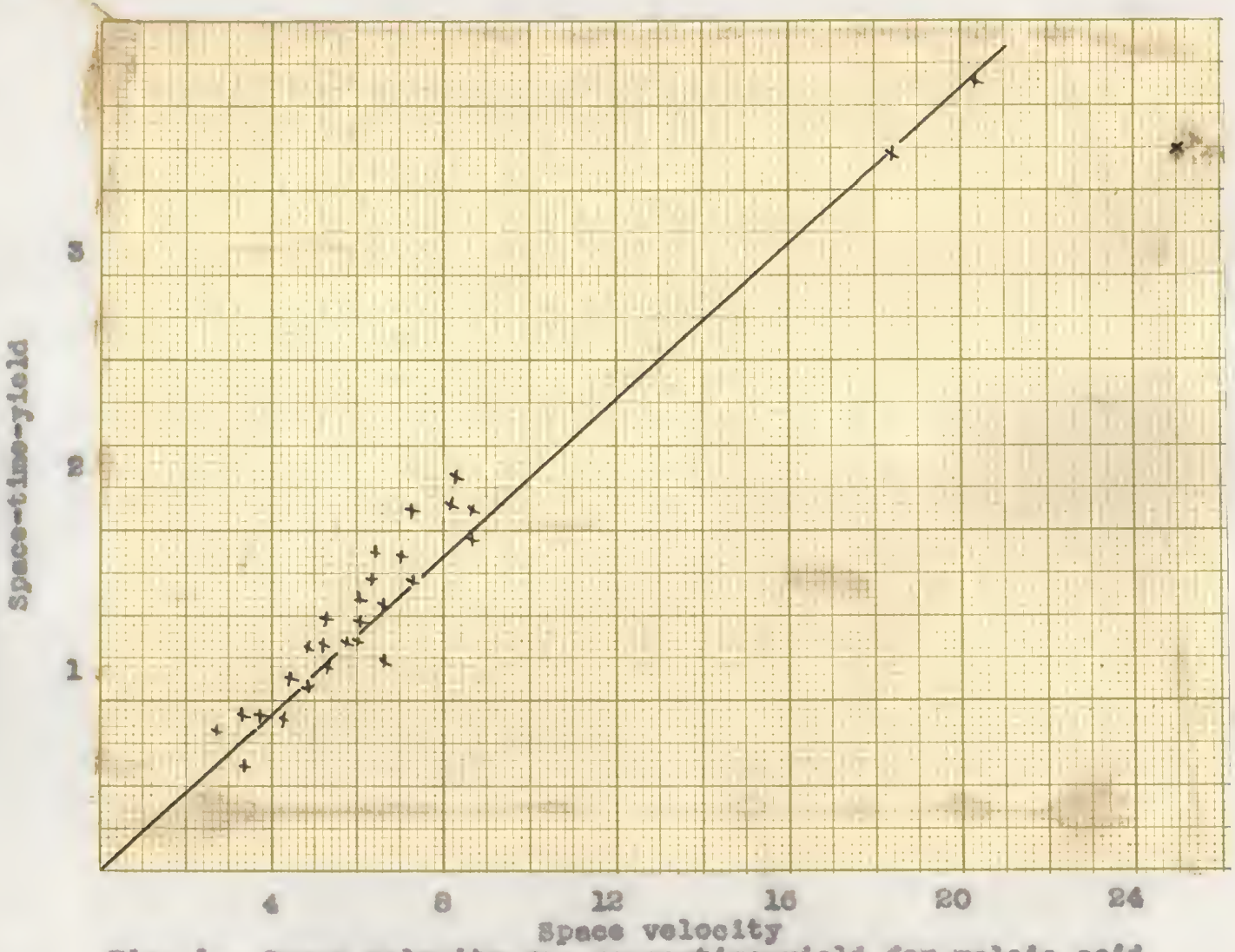

Fig. 1. Space velocity vs. space-time-yield for maleic acid from oxidation of amylene at 380 C.

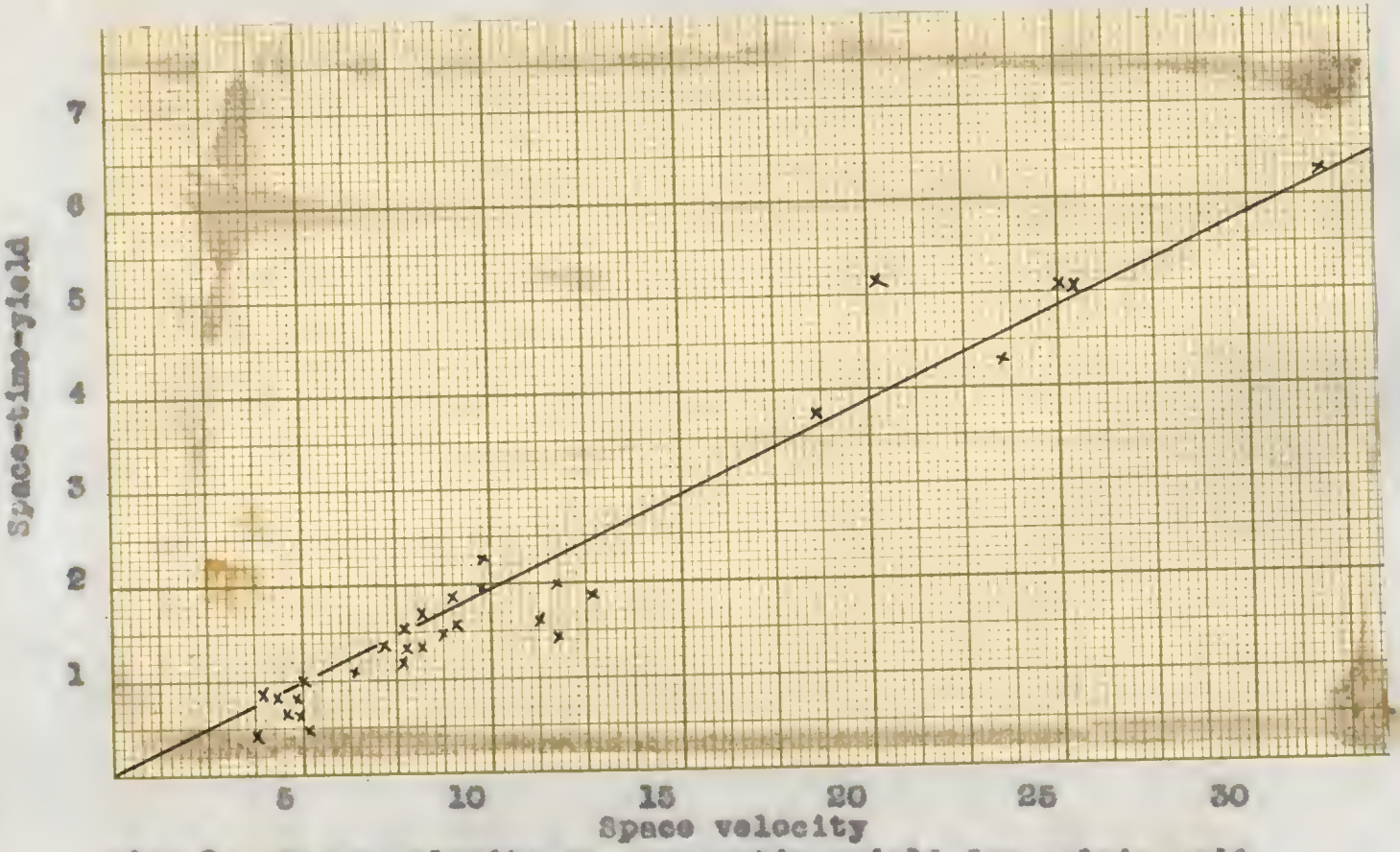

Fig. 2. Space velocity vs. space-time-yield for maleic acid from oxidation of amylene at 420° C.

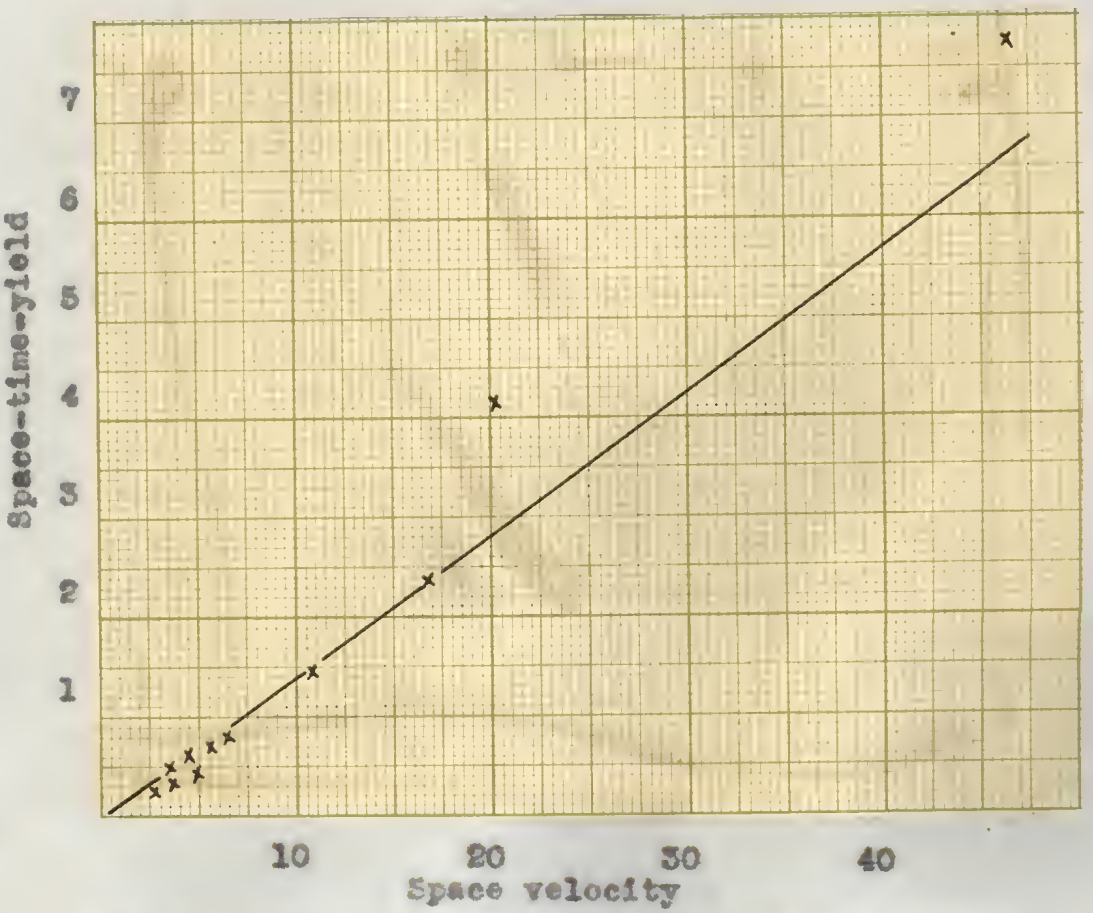

Fig. 3. Space-time-yield against space velocity for amylene oxidation to maleic acid at 465° C.

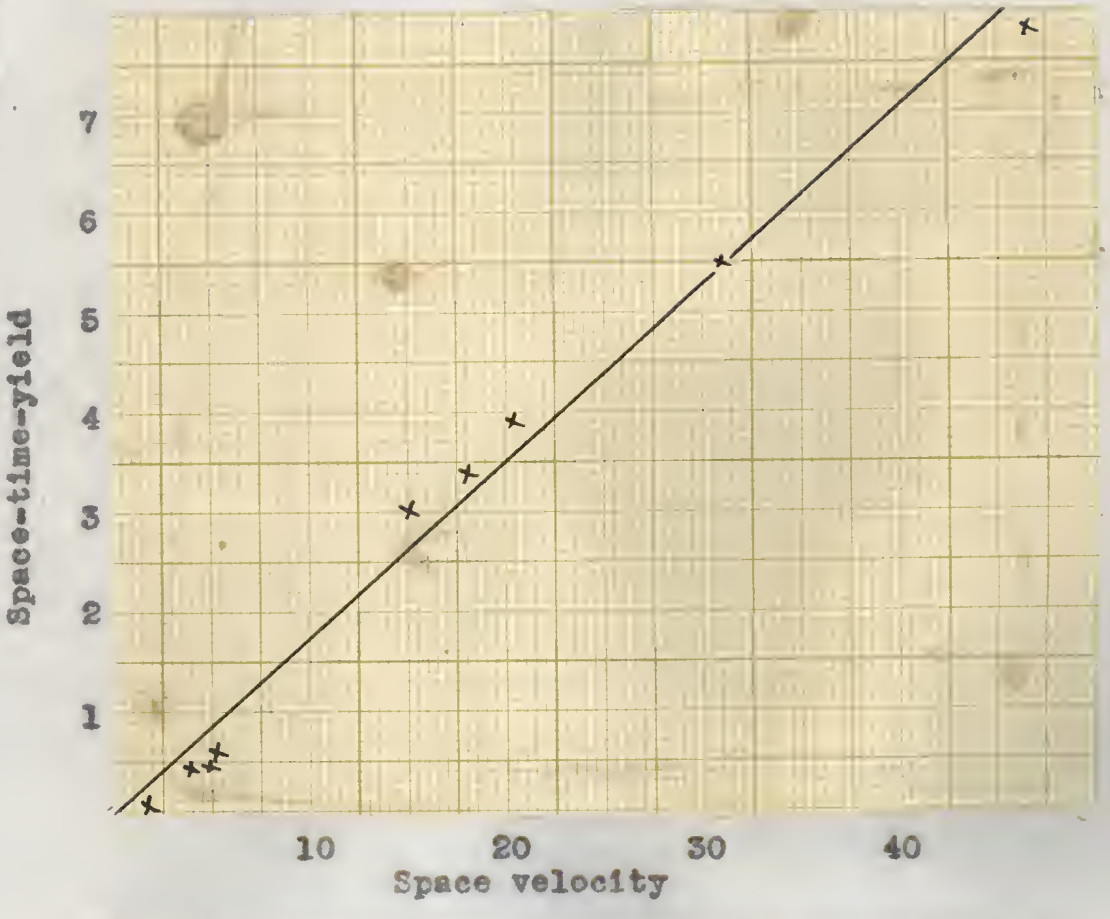

Fig. 4. Apace-time-yield against space velocity of amylene oxidat'on to meleic acid at 505° C.

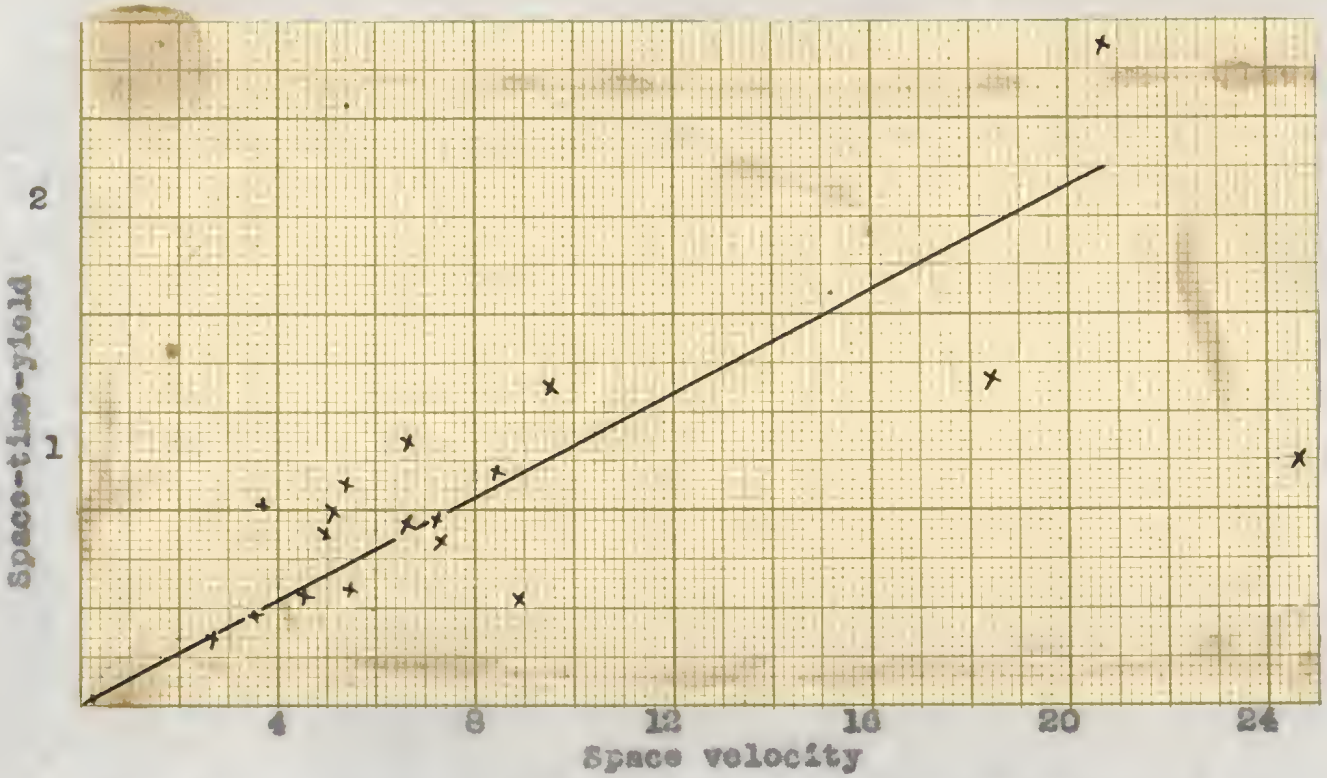

Fig. 5. Space-time-yield against space velocity for amylene oxidation to CO_2 at 380° C.

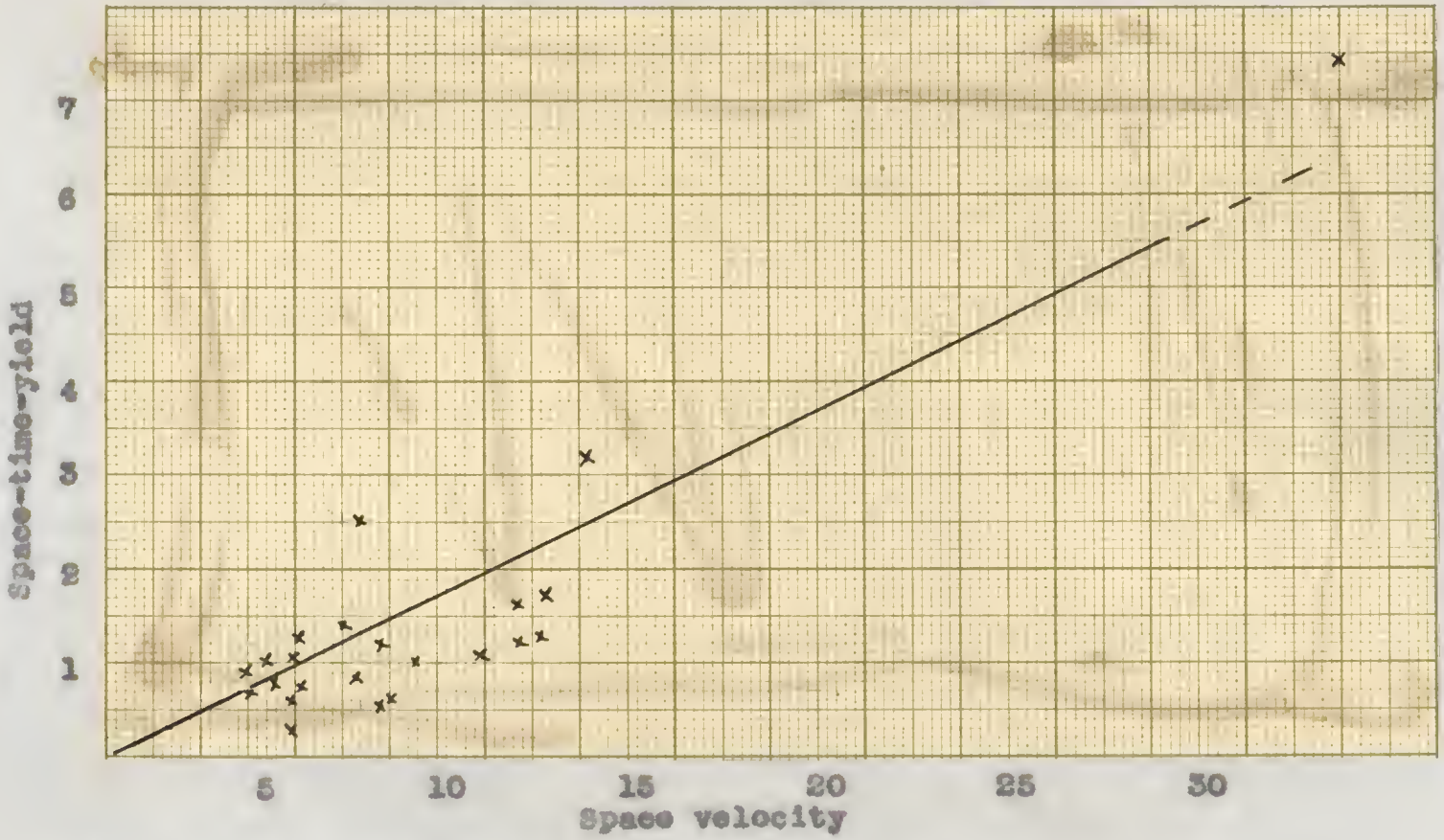

Fig. 6. Space-time-yield against space velocity of amylene oxidation to CO_2 at 420° C.

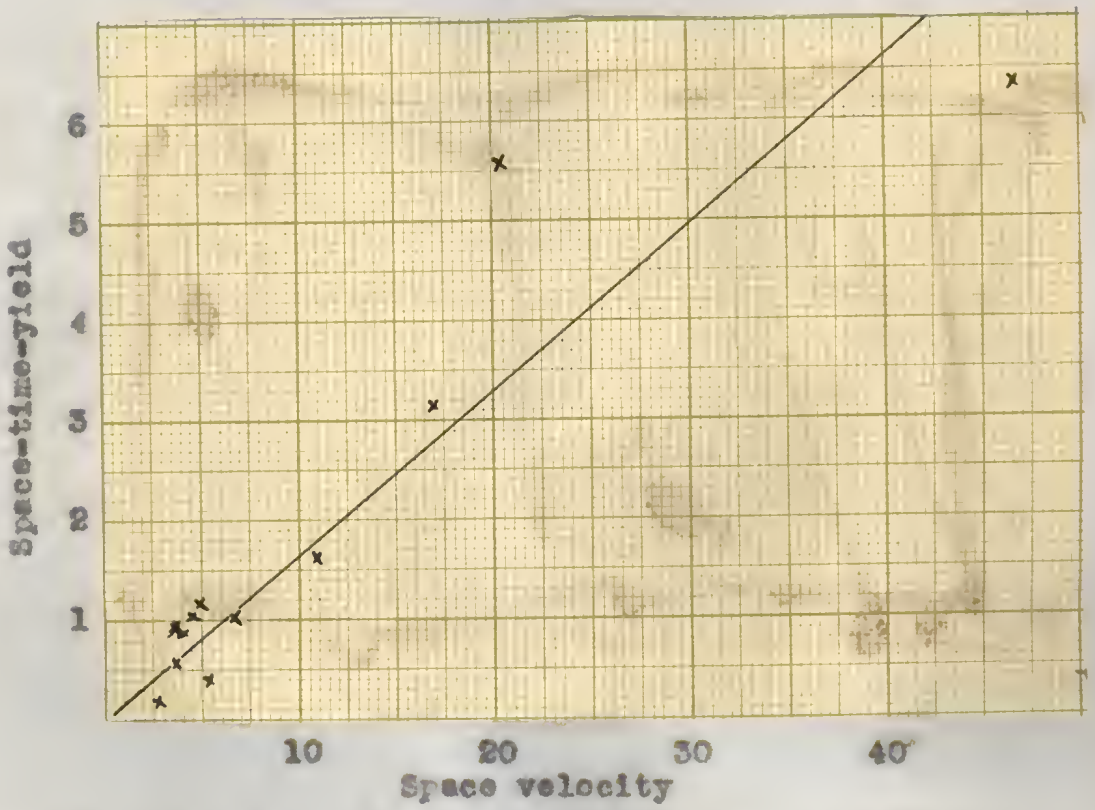

Fig. 7. Space-time-yield against space velocity of amylene oxidation to CO_2 at 465° C.

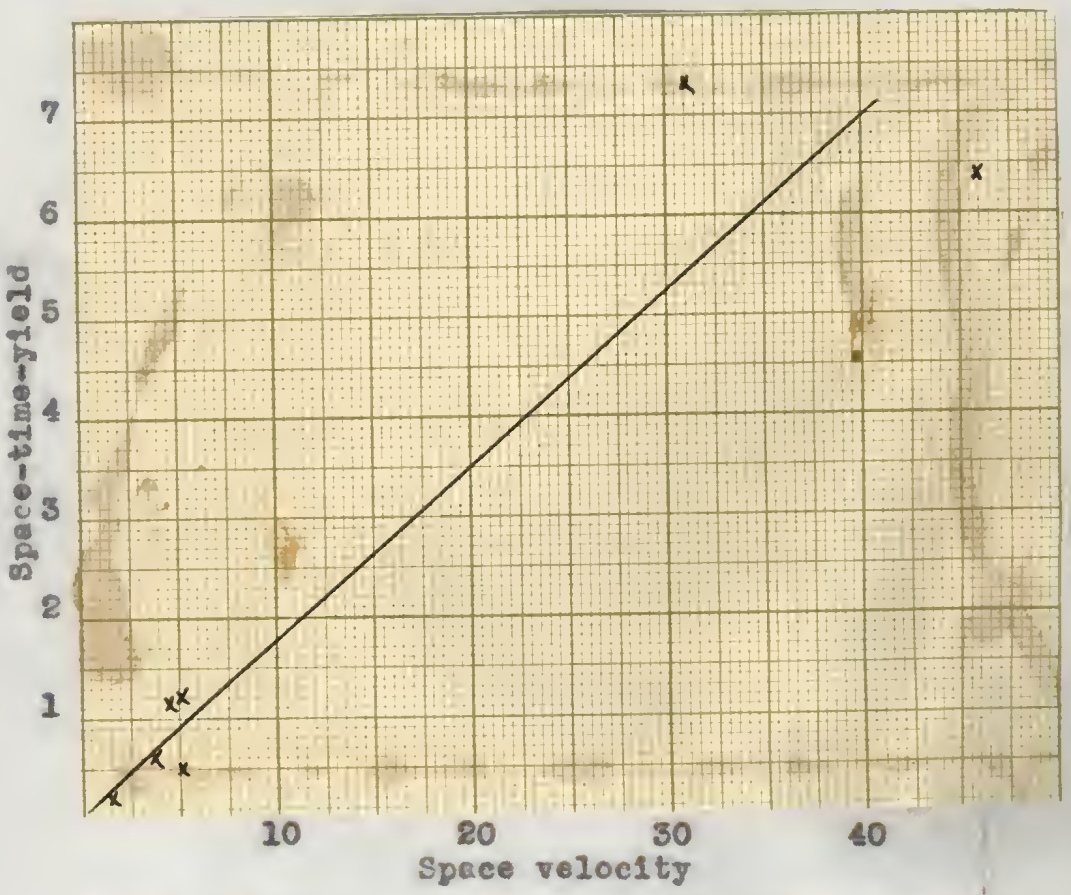

Fig. 8. Space-time-yield against space velocity for oxidation of amylene to CO_2 at 505° C.

The effect of space velocity on the space-time-yields of other acids is given by Figs. 9 to 12, inclusive. The conversions at 380°C. and 420°C., were 0.045, and 0.035, respectively. In each case, the spread is 0.3 space-time-yield units. However, at 465°C., and 505°C., several of the runs gave very small yields of other acids, and the plot is difficult to interpret. By giving weight to the runs at higher space velocity, conversions were obtained at 465°C., and 505°C. of 0.014 and 0.015, respectively.

Spreads for aldehydes in Figs. 13 to 16 are 0.3, 0.3, 0.5, and 1.0 for the temperatures 380°C., 420°C., 465°C., and 505°C., respectively. For the same temperatures, conversions were 0.14, 0.14, 0.09, and 0.18 moles of aldehyde per mole amylene for the increasing temperatures.

Effect of Air-Amylene Ratio

A large excess of air was used in all the runs. An optimum gas-hydrocarbon ratio was found for oxidations under similar conditions by Faith and Schaible (6) and by Faith and Yantzi (9). However, runs with amylene did not

show this effect clearly. It is possible that greater variation in air-amylene ratio would give a stronger trend. In Figs. 17, 18, and 19, plots of conversion to maleic acid and to CO_2 versus air-amylene ratio are given.

Effect of Length of Carbon Chain

The preliminary runs of higher molecular weight olefins show a definite increase in conversion to maleic acid. A mixture of several of these olefins gave maleic, but no attempt was made to calculate the yield. At 340°C., 380°C., and 420°C., the conversion to maleic acid from the oxidation of methyl pentene was 0.070, 0.239, and 0.257, respectively. Conversions of heptene were found at 340°C., 380°C., 420°C., and 505°., and were 0.105, 0.239, 0.266, 0.254, respectively. At these same temperatures, caprylene gave 0.163, 0.317, 0.297, 0.300, 0.306 moles of maleic acid per mole of olefin for the increasing temperatures used.

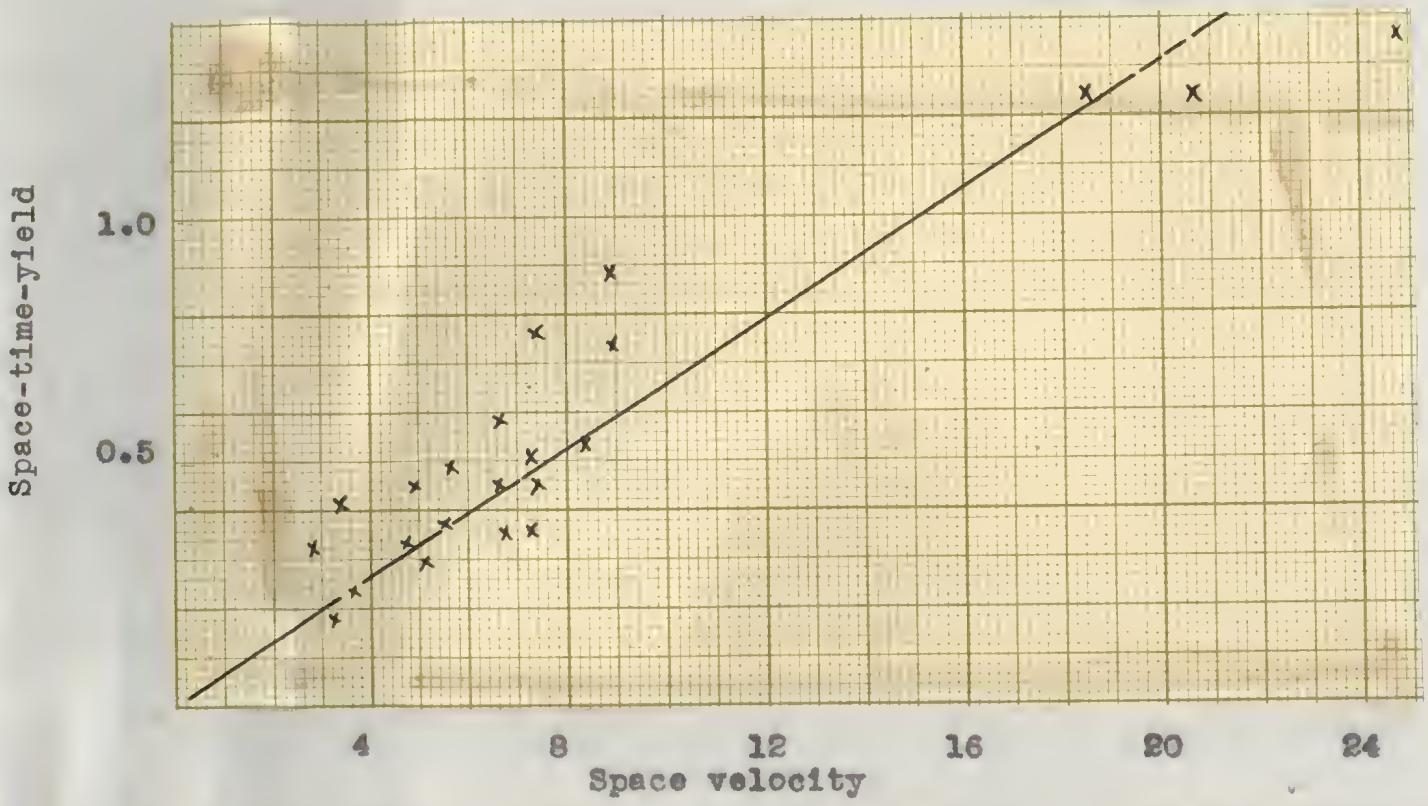

Fig. 9. Space-time-yield against space velocity of amylene oxidation to other acids at 380° C.

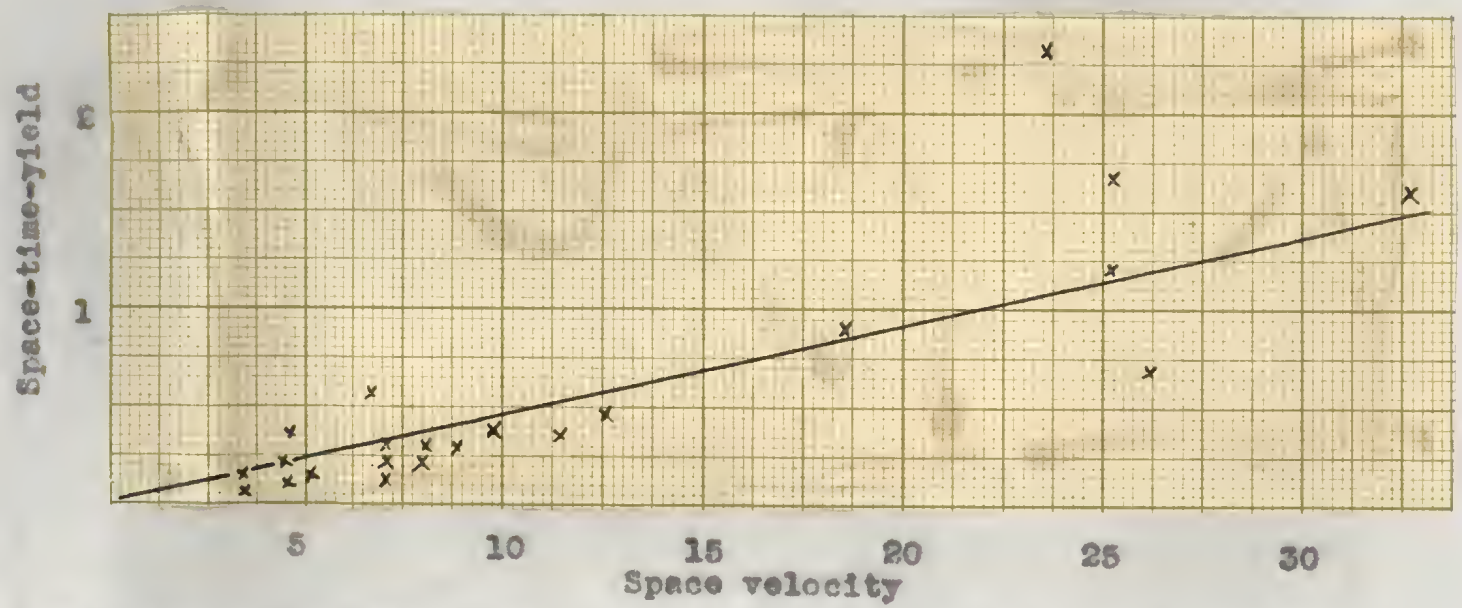

Fig. 10. Space-time-yield against space velocity of amylene oxidation to other acids at 420° C.

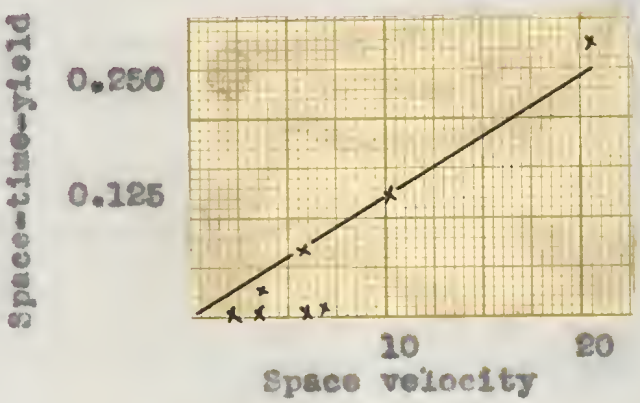

Fig. 11. Space-time-yield against space velocity of amylene oxidation to other acids at 465° C.

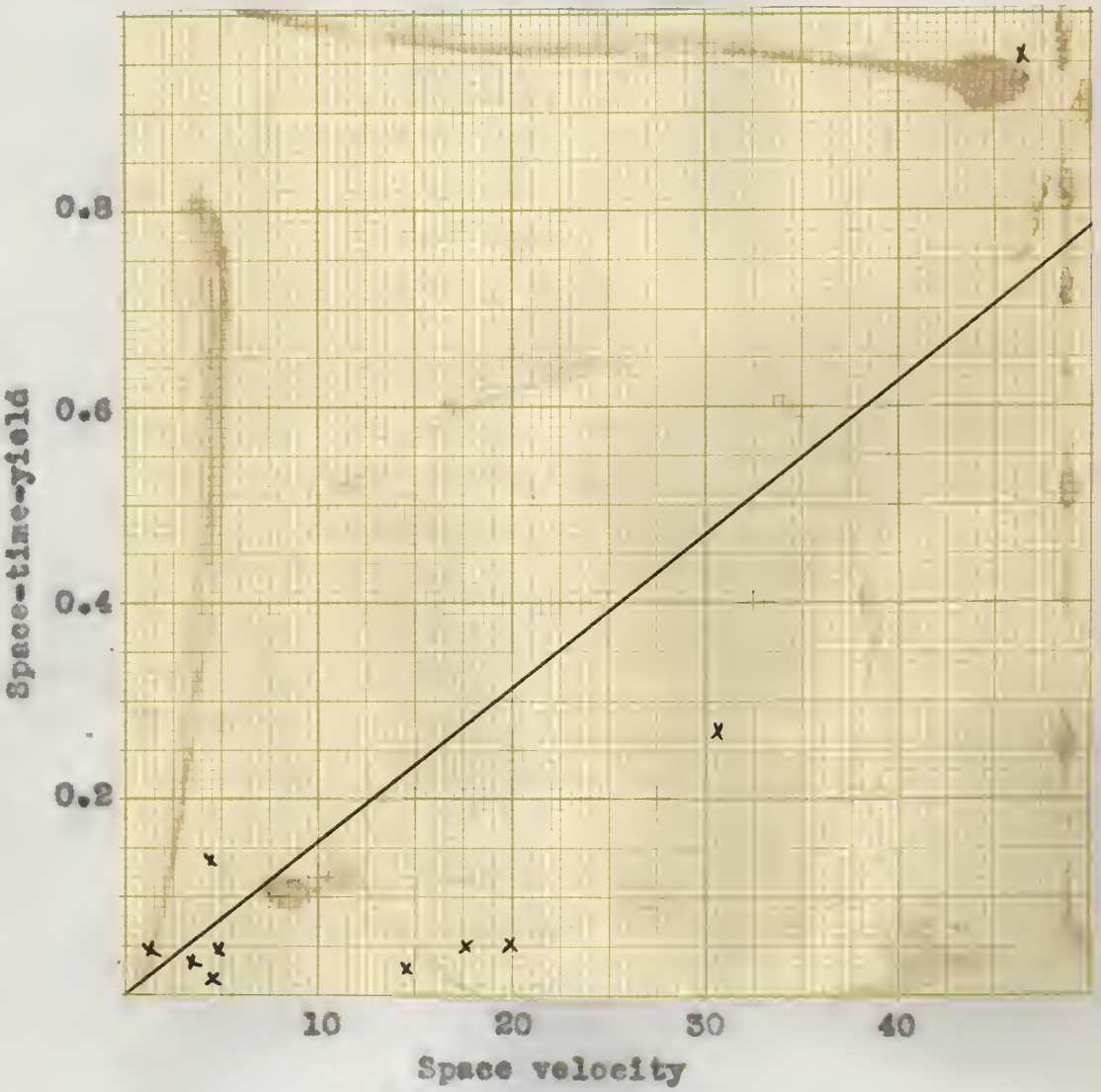

Fig. 12. Space-time-yield against space velocity of amylene oxidation to other acids at 505° C.

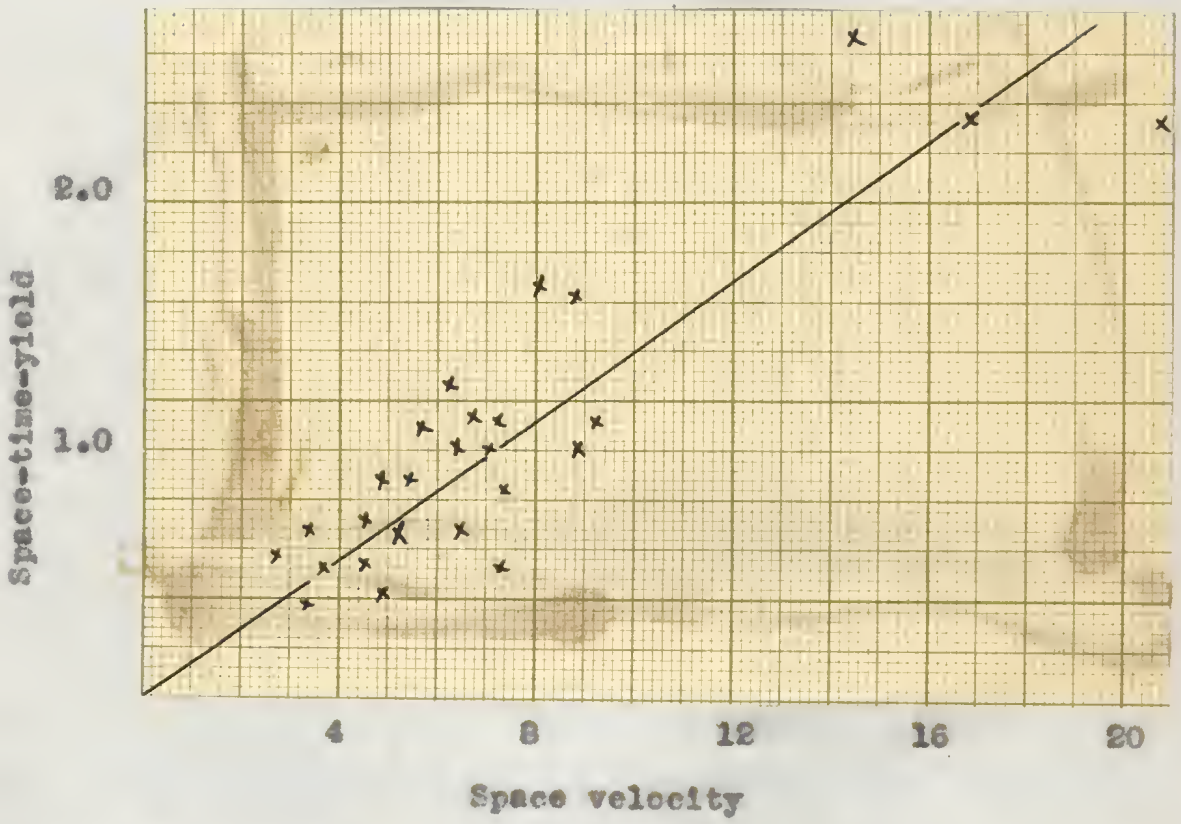

Fig. 13. Space-time-yield against space velocity of oxidation of amylene to aldehydes at 380° C.

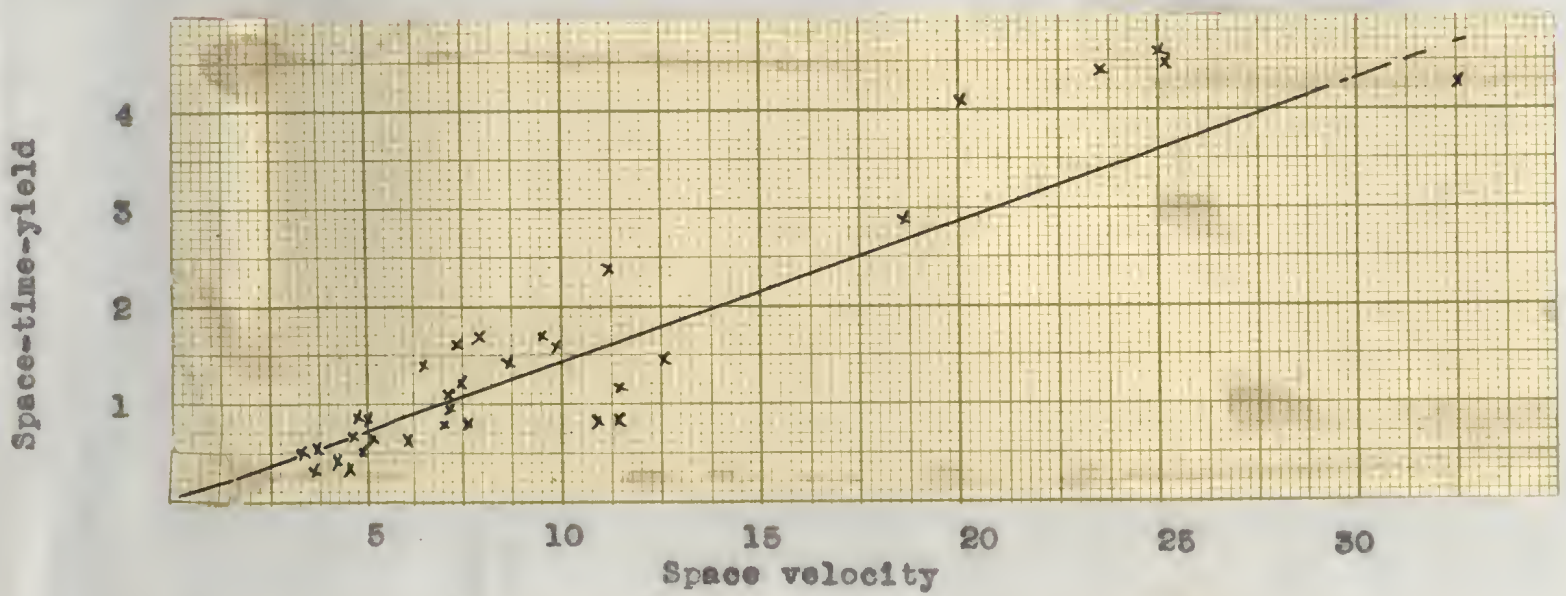

Fig. 14. Space-time-yield against space velocity of amylene oxidation to aldehydes at 420° C.

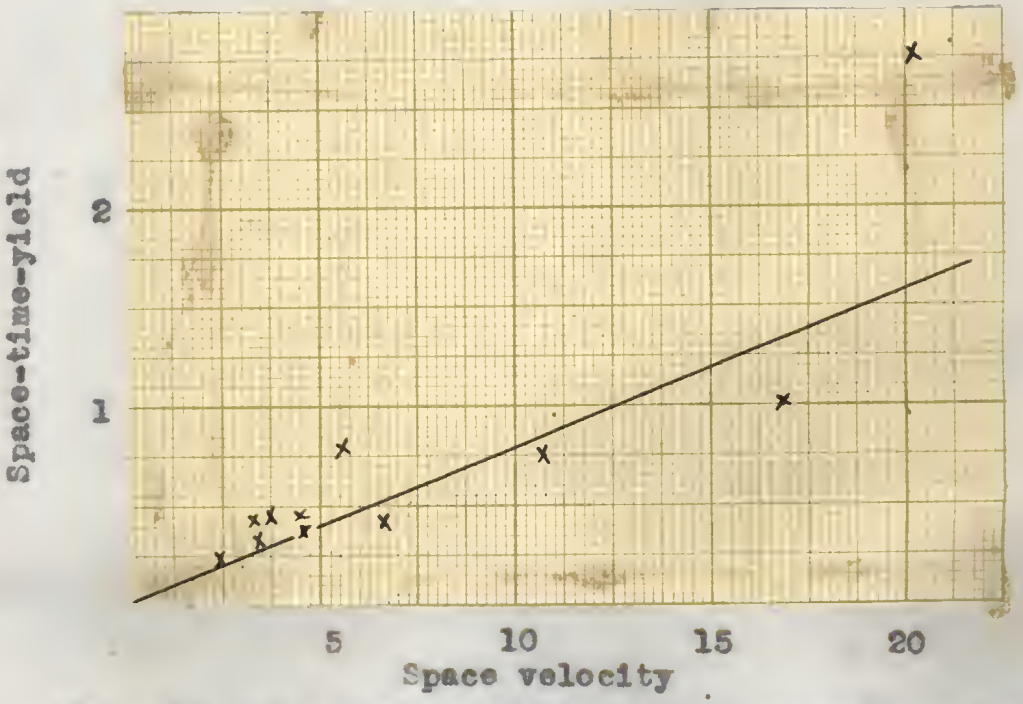

Fig. 15. Space-time-yield against space velocity of amylene oxidation to aldehydes at 465° C.

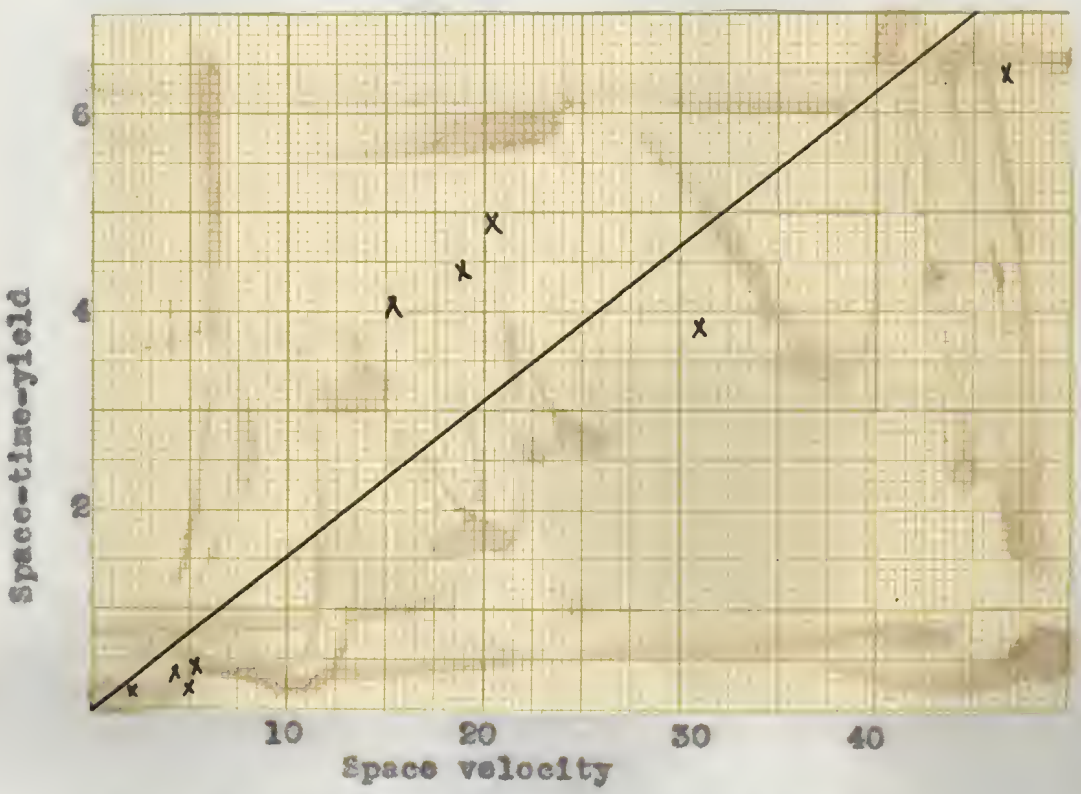

Fig. 16. Space-time-yield against space velocity of amylene oxidation to aldehydes at 505° C.

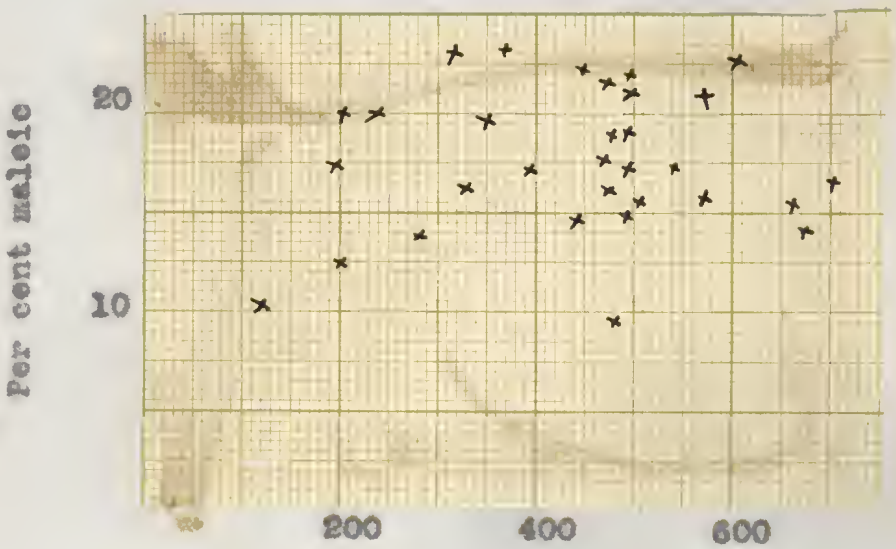

Fig. 17. Per cent maleic against air-amylene ratio for amylene oxidation at 420° C.

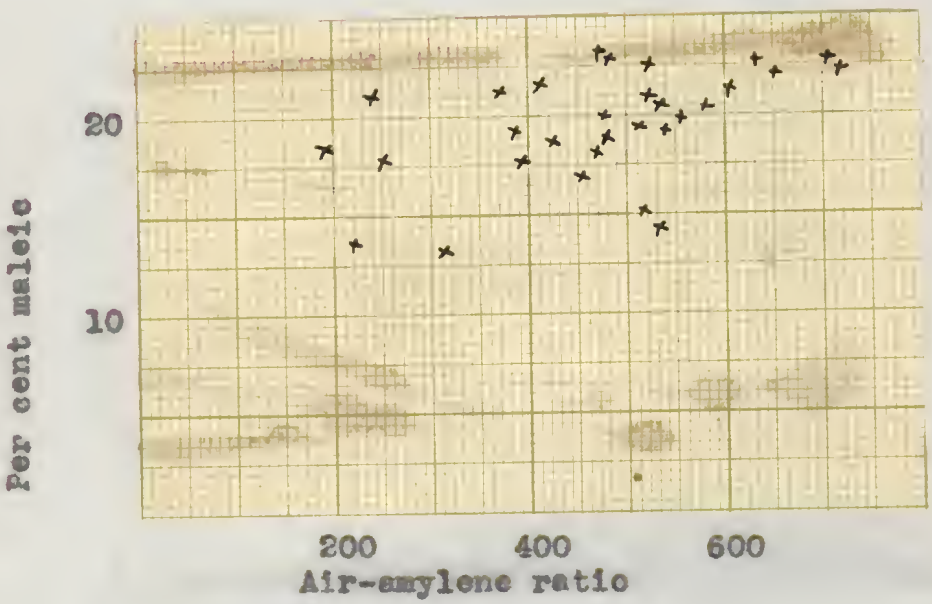

Fig. 18. Per cent maleic against air-amylene ratio of amylene oxidation at 380° C.

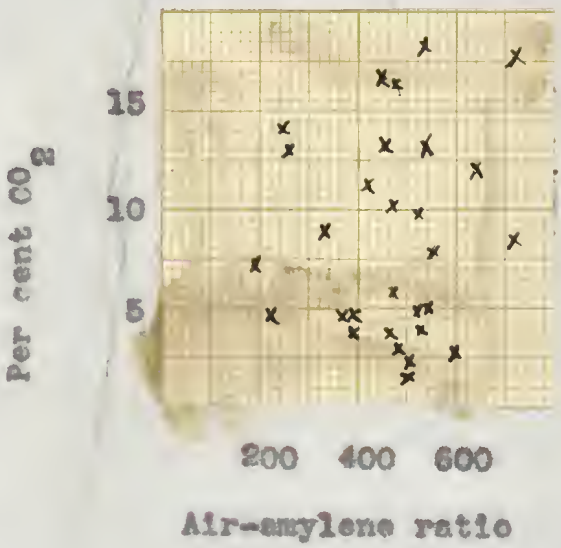

Fig. 19. Per cent CO_2 against air-amylene ratio of amylene oxidation at 380° C.

Effect of Length of Catalyst

For runs 119 to 132, the tube containing the catalyst was filled for 18 centimeters of its length. Runs 133 to 184 were made in the same tube with the catalyst extending 36 centimeters along the tube. Runs 185 to 197 were made with 25 centimeters of catalyst, while runs 198 to 208 were with 8 centimeters of catalyst. In each case, the same tube was used of 2.5 centimeters diameter. The averages which will be given in the following results were arithmetical. The average deviation in any one set of these conversions was about 0.03 moles of maleic per mole of amylene.

At 340°C., the conversion, when the catalyst tube was filled with 8, 18, 25, and 36 centimeters of catalyst, was 0.11, 0.06, 0.17, and 0.07, respectively. These are irregular with respect to length of catalyst. At 380°C., the conversions in the same order of increasing lengths were 0.21, 0.19, 0.20, and 0.18. It can be seen that a slightly better yield is obtained with the shorter catalysts.

At 420°C., the conversions were 0.19, 0.19, 0.20, and 0.17 for increasing length of catalyst. Thus, the

best conversion was at 25 centimeters. At 435 and 505°C., the conversions are available at 18 and 36 centimeters. At 465°C., the conversions were 0.18 and 0.14, and at 505°C. the conversions for the same lengths of catalyst were 0.19 and 0.10. Hence, at the higher temperatures, a long catalyst is a definite disadvantage.

SUMMARY

1. Optimum temperatures for the conversion of amylene were found to be between 380-420°C.

2. The activity of the catalyst was not decreased appreciably after 135 runs which averaged 2 hours in length.

3. The increase of space velocity based on amylene flow produced no decrease in conversion due to the catalyst's capacity being exceeded.

4. Preliminary runs on caprylene, heptene, and methyl pentene gave conversions of 0.297, 0.286, and 0.257 moles of maleic acid per mole olefin, respectively, at 420°C.

5. The length of catalyst was found to have some

effect at higher temperatures. That is, a shorter catalyst was beneficial.

ACKNOWLEDGMENT

The writer wishes to express his sincere appreciation to his major instructor, Dr. W. L. Faith, and to Dr. J. W. Greene, for their constant assistance and advice given during the course of his work.

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APPENDIX

Table 1. Conversions of amylene at 340° Centigrade.
Amylene = MC.

Run	Air : MC Ratio	Space velocity	Mole product per mole amylene: Maleic	CO_2	Other acids	Aldehydes
176	670	2.60	0.078	0.000	0.089	0.056
177	660	2.66	0.153	0.011	0.101	0.099
146	440	3.96	0.156	0.113	0.109	0.089
219	595	4.08	0.104	0.000	0.094	0.058
175	430	4.08	0.113	0.000	0.107	0.072
180	380	4.49	0.065	0.057	0.063	0.036
178	390	4.51	0.114	0.013	0.104	0.065
193	505	5.10	0.141	0.019	0.111	0.074
200	495	15.90	0.140	0.164	0.083	0.076
192	490	5.45	0.202	0.054	0.094	0.098
201	475	16.50	0.091	0.016	0.073	0.075
179*	300	5.85	0.026	0.057	0.036	0.013
174	290	6.25	0.062	0.021	0.060	0.035
173	280	6.50	0.078	0.002	0.068	0.038
194*	385	6.65	0.034	0.000	0.021	0.029
130	265	25.70	0.054	0.053	0.051	0.034

*These runs at 260° Centigrade.

Table 2. Conversions of amylene at 380° Centigrade.
Amylene = HC.

Run	Air/HC Ratio	Space velocity	Mole product per mole amylene: Maleic	CO_2	Other acids	Aldehydes
207	705	6.43	0.229	0.095	0.116	0.204
172	770	2.35	0.144	0.111	0.065	0.111
208	630	7.20	0.227	0.120	0.128	0.209
149	655	2.71	0.221	0.229	0.063	0.140
171	515	3.39	0.149	0.096	0.070	0.122
153	525	3.41	0.209	0.182	0.018	0.155
196	710	3.76	0.223	0.178	0.087	0.193
170	460	3.78	0.169	0.130	0.057	0.080
143	427	4.05	0.187	0.196	0.037	0.119
215	600	4.00	0.211	0.029	0.067	0.200
206	485	12.40	0.230	0.035	0.067	0.174
214	555	4.35	0.204	0.079	0.088	0.193
216	540	4.46	0.194	0.060	0.064	0.183
190	570	4.04	0.204	0.048	0.149	0.152
212	520	4.65	0.209	0.017	0.073	0.203
217	505	4.82	0.191	0.022	0.061	0.132
205	525	15.00	0.146	0.037	0.087	0.097
195	520	5.10	0.226	0.130	0.067	0.172
213	465	3.20	0.173	0.165	0.048	0.102
191	480	5.45	0.198	0.100	0.071	0.143
198	470	16.70	0.232	0.025	0.106	0.151
136	310	5.55	0.132	0.087	0.047	0.070
199	473	16.80	0.188	0.056	0.059	0.108
220	410	6.15	0.213	0.112	0.065	0.207

Table 2. (cont.).

Run	Air/HC Ratio	Space velocity	Mole product per mole amylene: Maleic	CO_2	Other acids	Aldehydes
221	375	6.70	0.211	0.047	0.102	0.183
189	395	6.76	0.176	0.039	0.084	0.115
222	390	6.84	0.186	0.045	0.082	0.112
136	240	7.00	0.208	0.140	0.049	0.121
223	195	14.10	0.183	0.070	0.057	0.144
127	250	15.90	0.176	0.129	0.051	0.112
126	215	18.80	0.137	0.041	0.056	0.094

Table 3. Conversions of amylene at 420° Centigrade.
Amylene = HC.

Run	Air / HC Ratio	Space velocity	Mole product per mole amylene: Maleic	CO_2	Other acids	Aldehydes
157	635	2.70	0.143	0.269	0.010	0.071
161	660	2.72	0.152	0.180	0.030	0.144
147	605	2.90	0.228	0.207	0.000	0.145
148	570	3.00	0.209	0.146	0.000	0.107
163	665	3.16	0.155	0.239	0.013	0.126
159	540	3.22	0.174	0.262	0.011	0.124
162	535	3.30	0.173	0.106	0.014	0.141
158	490	3.50	0.171	0.183	0.000	0.074
165	500	3.56	0.147	0.201	0.039	0.120
151	475	3.62	0.190	0.231	0.020	0.126
164	490	3.65	0.156	0.141	0.006	0.113
144	475	3.70	0.096	0.124	0.004	0.051
156	475	3.67	0.162	0.205	0.014	0.105
204	700	11.20	0.169	0.063	0.074	0.163
160	470	3.78	0.174	0.255	0.030	0.096
150	390	4.53	0.172	0.237	0.024	0.107
210	495	4.89	0.219	0.125	0.009	0.232
140	325	5.28	0.165	0.308	0.023	0.125
180	595	5.45	0.212	0.086	0.033	0.172
203	495	16.20	0.177	0.003	0.046	0.130
141	315	5.42	0.231	0.085	0.020	0.147

Table 3. (cont.).

Run	Air/HC Ratio	Space velocity	Mole product per mole amylene: Maleic	CO_2	Other acids	Aldehydes
197	465	5.47	0.157	0.168	0.002	0.152
211	435	5.60	0.216	0.079	0.023	0.215
139	230	5.95	0.107	0.448	0.025	0.098
187	445	6.15	0.223	0.130	0.048	0.213
185	395	6.80	0.173	0.000	0.033	0.161
186	365	7.42	0.231	0.080	0.003	0.177
202	350	22.40	0.194	0.105	0.037	0.170
209	465	8.20	Missed	0.024	Missed	0.233
137	210	8.36	0.132	0.143	0.013	0.088
133	200	8.62	0.124	0.115	0.000	0.053
136	196	8.75	0.174	0.157	0.031	0.103
122	435	9.70	0.148	0.255	0.037	0.117
121	260	14.20	0.200	Missed	0.049	0.153
129	270	15.30	0.256	0.072	0.054	0.202
119	225	18.00	0.161	Missed	0.059	0.187
120	200	19.10	0.202	0.024	0.056	0.163
123	215	19.20	0.139	Missed	0.049	0.176
128	120	30.30	0.102	Missed	0.024	0.078
124	165	24.90	0.192	0.229	0.049	0.135

Table 4. Conversions of amylene at 485° Centigrade.
Amylene = HC.

Run	Air/HC Ratio	Space velocity	Mole product per mole amylene: Maleic	CO_2	Other acids	Aldehydes
152	800	2.02	0.124	0.054	0.003	0.021
168	650	2.76	0.156	0.144	0.003	0.111
166	650	2.78	0.171	0.212	0.008	0.115
167	640	2.82	0.124	0.250	0.002	0.0[illegible]
169	545	3.33	0.138	0.211	0.003	0.094
154	515	3.50	0.157	0.221	0.000	0.000
145	470	3.75	0.114	0.228	0.001	0.060
018	465	5.21	0.149	0.066	0.014	0.145
142	350	4.90	0.141	0.152	0.004	0.062
137	210	8.38	0.132	0.143	0.012	0.068
134	135	13.00	0.147	0.186	0.000	0.059
132	260	15.70	0.209	0.270	0.015	0.136
125	110	36.30	0.138	0.136	0.020	0.137

Table 5. Conversions of amylene at 505° Centigrade.
Amylene = HC.

Run	Air : HC Ratio	Space velocity	Mole product per mole amylene: Maleic	CO_2	Other acids	Aldehydes
183	1450	1.20	0.056	0.088	0.026	0.097
184	570	2.95	0.114	0.140	0.008	0.097
155	485	3.60	0.096	0.232	0.028	0.042
145	470	3.75	0.114	0.228	0.001	0.050
182	450	3.77	0.120	0.211	0.005	0.084
181	430	3.92	0.097	0.088	0.008	0.081
255	265	13.10	0.202	Missed	0.013	0.270
256	235	15.70	0.186	Missed	0.030	0.246
254	210	17.70	0.195	Missed	0.023	0.245
131	175	23.80	0.177	0.235	0.009	0.126
125	110	33.30	0.168	0.136	0.020	0.137

Table 6. Conversions of methyl pentene at 340-420° Centigrade.
Methyl Pentene = MP.

Run	Air / MP Ratio	Space velocity	Mole product per mole methyl pentene: Maleic	CO_2	Other acids	Aldehydes	Temperature degree Centigrade
230	480	8.95	0.100	0.066	0.060	0.052	340
229	390	11.20	0.048	0.012	0.033	0.032	340
224	2700	1.37	0.233	Missed	0.072	0.186	380
225	1300	3.02	0.245	0.076	0.091	0.173	380
228	895	4.80	0.239	0.076	0.068	0.148	380
227	950	4.42	0.226	0.087	0.053	0.144	420
226	470	8.87	0.267	0.120	0.061	0.194	420
231	375	11.10	0.279	0.083	0.039	0.209	420

Table 7. Conversions of heptene at 340-505° centigrade.
Heptene = HE.

Run	Air / HE Ratio	Space velocity	Mole product per mole heptene: Maleic	CO_2	Other acids	Aldehydes	Temperature degree Centigrade
236	750	5.48	0.105	0.055	0.070	0.078	340
234	2060	2.02	0.247	0.064	0.053	0.206	380
233	1370	3.35	0.233	0.064	0.067	0.158	380
235	940	4.43	0.254	0.104	0.056	0.195	380
239	700	6.27	0.244	0.180	0.062	0.159	380
232	3600	1.10	0.208	Missed	0.000	0.122	380
238	1340	2.90	0.272	0.175	0.033	0.234	420
237	680	5.90	0.261	0.194	0.038	0.184	420
241	960	4.46	0.238	0.206	0.060	0.208	465
240	715	5.70	0.270	0.337	0.018	0.205	465
242	550	7.58	0.259	0.230	0.012	0.186	505

Table 8. Conversions of caprylene at 340-505° Centigrade.
Caprylene = CA.

Run	Air/CA Ratio	Space velocity	Mole product per mole caprylene: Maleic	CO_2	Other acids	Aldehydes	Temperature degree Centigrade
249	485	8.52	0.183	0.036	0.064	0.229	340
246	2400	1.78	0.310	0.074	0.025	0.300	380
247	1980	2.30	0.323	0.260	0.067	0.251	380
245	1790	2.46	0.327	0.230	0.026	0.327	420
244	1310	3.28	0.315	0.160	0.032	0.256	420
248	430	9.30	0.280	0.165	0.061	0.222	420
251	455	9.10	0.300	0.237	0.030	0.318	465
250	445	9.30	0.306	0.245	0.004	0.282	505